Technical Report (not peer reviewed)

Overview of the acoustic studies on large whales conducted by the Institute of Cetacean Research: Case study of fin whales off northern Japan

Hiroko YAMADA and Taiki KATSUMATA*

Institute of Cetacean Research, 4–5 Toyomi-cho, Chuo-ku, Tokyo 104–0055, Japan

**Contact e-mail: katsumata@cetacean.jp*

ABSTRACT

The Institute of Cetacean Research (ICR) initiated passive acoustic monitoring (PAM) as a pilot study to address observational gaps of large whales in northern Japan during boreal winter months when weather conditions constrain visual surveys from specialized vessels. This paper presents the results of a pilot study focused on fin whale (*Balaenoptera physalus*). The occurrence of this species in northern Japan was investigated using autonomous acoustic recorders deployed in Ōhata, Aomori Prefecture, from 26 November to 25 December 2024. A total of 4,567 fin whale calls were detected, showing pronounced nighttime activity (18:00–08:00). The results of this pilot study demonstrated PAM's effectiveness for detecting the occurrence of large whales in winter in northern Japan. Further studies are planned to evaluate the feasibility of this approach to estimate whale density.

INTRODUCTION

The Institute of Cetacean Research (ICR) has been conducting long-term monitoring of cetacean populations in the North Pacific Ocean to contribute to the scientific understanding and resource management of the large baleen whale species (Tamura *et al.*, 2017). Dedicated sighting surveys by specialized vessels are valuable for estimating abundance and investigating their distribution. However, visual survey faces significant limitations during autumn and winter months in the North Pacific due to adverse weather conditions, limited daylight hours, and sea state constraints (Katsumata and Matsuoka, 2021). To address these observational gaps and enhance the temporal coverage of the large baleen whale species monitoring, the ICR has initiated passive acoustic monitoring (PAM) as a pilot study to investigate the feasibility of this approach to complement the routine visual surveys by research vessels.

Previous PAM studies in Japanese coastal waters have demonstrated the potential of this approach for acoustic detection of baleen whales. For example, low-frequency fin whale calls have been detected by seafloor cabled seismic networks and regional broadband sensors (Nishida *et al.*, 2016; Sugioka *et al.*, 2015), including areas near the Pacific coast of northern Japan. While these systems offer high temporal resolution and sensitivity in low-frequency bands, they are primarily designed for geophysical monitoring and thus lack the species-specific detection capabilities, deployment flexibility, and data accessibility needed for targeted ecological studies. To complement the long-term monitoring of baleen whale species by visual surveys, the ICR conducted a pilot passive acoustic monitoring survey in Ōhata, Aomori Prefecture, Japan, from late November to late December 2024. In this paper, we report on the results of the pilot study.

The pilot study was focused on fin whales (*Balaenoptera physalus*). This species produces a distinctive vocal repertoire that includes low-frequency (~20 Hz) downswept pulses and occasional mid-frequency (~130 Hz) upsweep calls. The 20-Hz pulses—often referred to as "20-Hz calls" or "notes"—are short (typically <1 s) and highly stereotyped, occurring in regular sequences that can propagate over tens to hundreds of kilometers in the ocean due to their low-frequency nature and high source levels (Širović *et al.*, 2007; Watkins, 1981; Watkins *et al.*, 1987). These calls are commonly made by males and are considered to play a role in reproductive and long-range communication(Clark and Ellison, 2004; Croll *et al.*, 2002; Watkins *et al.*, 1987). Their detectability and consistency make fin whales particularly well-suited for PAM studies. Accordingly, in the North Pacific, PAM-based studies have successfully documented fin whale vocal activity in remote or harsh environments such as the Bering Sea, Gulf of Alaska, and southern Chukchi Sea (Delarue *et al.*, 2009; Furumaki *et al.*, 2021; Stafford *et al.*, 2007; Tsujii *et al.*, 2016), and more broadly in the Southern Ocean(Leroy *et al.*, 2016).

MATERIALS AND METHODS

Data Collection

Between 26 November and 25 December 2024, we deployed a passive acoustic recorder (AUSOMS-mini Plus, model AQM-0007; AquaSound Inc., Japan) in the coastal waters off Ōhata, Aomori Prefecture, Japan, to monitor the vocal activity of fin whales. The hydrophone was installed on the continental shelf at a depth of 29.2 meters, and its location (41°34′55.92″N, 141°13′4.08″E) is shown in Figure 1.

The deployment procedure and the acoustic recorder unit are illustrated in Figures 2 and 3, respectively. The recording system was deployed using a subsurface mooring configuration arranged by a commercial contractor. The system was designed to ensure recording stability and minimize flow noise during the observation period. The AUSOMS-mini Plus operated in continuous mono recording mode at a sampling rate of 48 kHz. The hydrophone featured a frequency response range of 10 Hz to 20 kHz and a receiving sensitivity of −193 dB re 1 V/μPa. Calibration was performed prior to deployment in accordance with the manufacturer′s specifications.

The recording was conducted in two consecutive phases. The first phase lasted from 26 November to 25 December 2024, totaling 339 hours, 29 minutes, and 57 seconds. The second phase spanned from 10 to 25 December 2024, totaling 363 hours, 33 minutes, and 29 seconds. A hydrophone replacement was carried out between the two phases, resulting in a recording gap of approximately two hours. The procedure was performed to minimize interruption of acoustic data acquisition. All recordings were successfully retrieved for subsequent analysis.

The collected acoustic data were processed with a focus on the low-frequency components, characteristic of fin whale vocalizations. As part of the preprocessing, the data were downsampled to 500 Hz and subjected to a band-pass filter at 15 Hz to 40 Hz that eliminated low and middle frequency background noise. Subsequent analyses aimed to detect ~20 Hz pulses (approximately 17–30 Hz) as previously described by Watkins *et al.* (1987) and Širović *et al.* (2007).

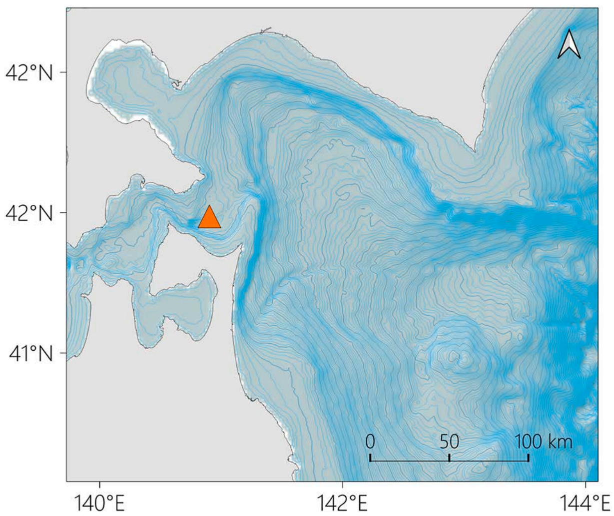

Figure 1. Map of the study area showing the deployment location of the passive acoustic recorder (AUSOMS-mini Plus, model AQM-0007; AquaSound Inc., Japan) in the coast of Ōhata, northern Japan. The recorder was moored at a depth of 29.2 meters on the continental shelf (41°34′55.92″N, 141°13′4.08″E), as indicated by the orange triangle.

Data analysis

Spectral analysis was conducted in a two-step process to effectively identify and characterize fin whale vocaliza-

Figure 2. Deployment of the AUSOMS-mini Plus passive acoustic recorder in Ōhata, Aomori Prefecture, Japan. The recorder was lowered from a research vessel and installed at a depth of 29.2 meters using a mooring configuration.

Figure 3. Close-up view of the AUSOMS-mini Plus recorder before deployment. The unit is enclosed in a protective frame and equipped for subsurface mooring.

tions. First, long-term spectral averages (LTSAs) were generated using TRITON, a custom MATLAB-based software developed by Scripps Institution of Oceanography, CA, US (Wiggins and Hildebrand, 2007). These LTSAs provided an overview of the temporal distribution and frequency ranges of prominent acoustic signals over multi-hour to multi-day time scales, enabling efficient identification of time windows likely to contain fin whale calls. Based on the LTSA results, segments containing potential vocalizations were subjected to detailed analysis using Avisoft-SASLab Pro (ver. 5.2.09; Avisoft Bioacoustics, Berlin, Germany). Prior to analysis, a band-limited filter was applied to isolate the frequency range of interest (typically 17–30 Hz for fin whale 20 Hz calls). The detection threshold was set to −14 dB relative to the maximum, with a minimum hold time of 20 ms, ensuring consistent element separation and reducing false detections.

For each detected pulse, spectral parameters such as peak frequency, minimum and maximum frequency, bandwidth, and peak amplitude were automatically extracted. Temporal parameters including element duration and inter-call interval were also computed.

Spectrograms were computed using a 1024-point fast Fourier transform (FFT) with a Hamming window and 87.5% overlap, yielding a frequency resolution of 1 Hz and temporal resolution of approximately 10.7 milliseconds. This configuration was selected to optimize detection of short-duration low-frequency signals. The temporal distribution of calls was visualized as heatmaps using Python (JupyterLab v4.3.1) and the ggplot2 package (Gómez-Rubio, 2017), allowing for the identification of diel and day-scale variability in vocal activity.

RESULTS

Acoustic identification of fin whale calls

Representative spectrograms extracted from the dataset (Figure 4) displayed repeated low-frequency pulses around 20 Hz occurring at regular intervals—an acoustic pattern widely recognized as characteristic of fin whale vocalizations (e.g., Moore *et al.*, 1998; Širović *et al.*, 2007). Although the spectrogram alone does not conclusively determine species identity, the observed regularity in both frequency and temporal spacing provided preliminary evidence supporting classification as fin whale calls.

To validate this interpretation, we conducted quantitative analyses of the detected signals′ acoustic features. First, the distribution of peak frequencies was tightly clustered around 18.7 Hz, with most values falling between 15 and 25 Hz, matching the well-documented spectral characteristics of fin whale calls reported in earlier studies (e.g., Moore *et al.*, 1998; Širović *et al.*, 2007; Tsujii *et al.*, 2016). This distribution is visualized in Figure 5a. In addition, the calls exhibited short durations, with a median of approximately 0.7 seconds, and a strongly right-skewed distribution (range: 0.2–2.0 s). This duration profile was well-approximated by a Weibull probability density function, as shown in Figure 5b, consistent with previously reported pulse durations for fin whale signals. Furthermore, the inter-call intervals (ICIs) ranged from 10 to 60 seconds, with a mode near 15 seconds, and a long-tailed distribution pattern. This structure is shown in Figure 5c, and it reflects the rhythmic repetition that is characteristic of fin whale stereotyped song sequences.

The results of the acoustic survey were corroborated by visual confirmation of fin whale presence in the same region during a ship-based sighting survey conducted in the autumn of 2019 (October–November), as reported by Katsumata and Matsuoka (2021). This independent visual record serves as external validation for attributing the recorded vocalizations to fin whales. In addition to the strong agreement of acoustic features—such as frequency, duration, and inter-call interval—with established characteristics of fin whale calls, the spectrograph-

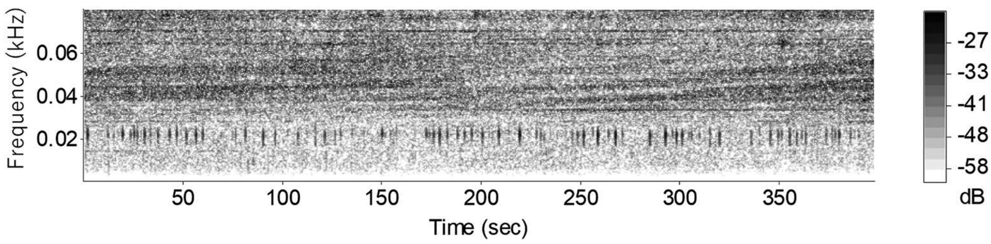

Figure 4. Long-duration spectrogram of fin whale calls recorded off Ōhata, Aomori Prefecture, Japan, in winter 2024. Spectral analysis was performed using a 1024-point Fast Fourier Transform (FFT) with a Hamming window, 75% overlap, and a frame advance of 100 samples. Repeated low-frequency pulses (~20 Hz) with regular spacing are visible throughout the 6-minute segment, characteristic of fin whale stereotyped song patterns.

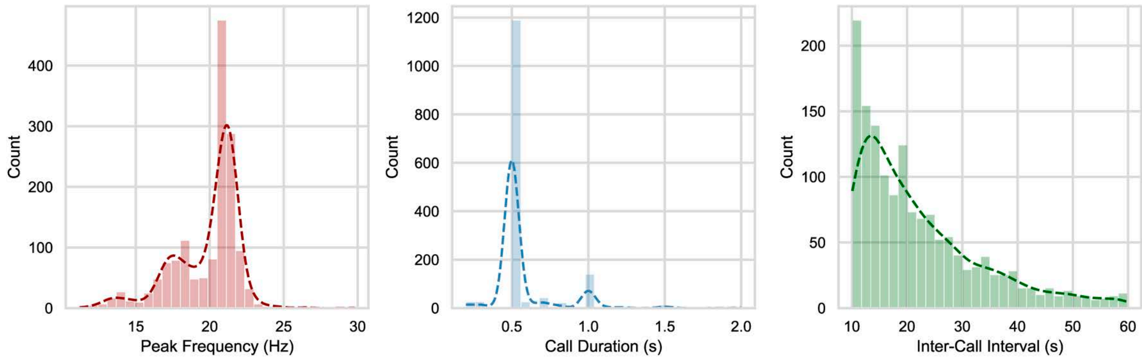

Figure 5. Distributions of acoustic parameters for detected fin whale 20 Hz pulses. (a) Peak frequency (Hz): the majority of calls exhibited peak frequencies clustered around 18.7 Hz, consistent with known fin whale vocalizations; (b) Call duration (s): most pulses were short in duration, with a median of 0.7 s and values typically falling between 0.2 and 2.0 s; (c) Inter-call interval (s): temporal spacing between calls ranged from 10 to 60 s, with a mode near 15 s, reflecting stereotyped rhythmic sequences. All histograms are overlaid with kernel density estimation (KDE) curves to illustrate overall distribution shape.

ic analysis and corresponding visual observations further reinforce this conclusion, providing robust evidence for identifying the detected vocalizations as those produced by fin whales.

Temporal distribution of fin whale calls

During the initial recording period from 26 November to 25 December 2024, a total of 4,567 fin whale calls were detected, revealing pronounced diel variability in vocal activity. Hourly detection counts indicated discrete periods of heightened acoustic activity, with particularly elevated call rates (>300 detections per hour) observed during the evening to early morning hours (18:00–08:00) on 7, 9, 10 and 11 December (Figure 6). These nocturnally concentrated call bouts may reflect diel patterns in behavioral states such as social interaction or foraging, or alternatively, improved acoustic transmission conditions during nighttime. Transient daytime peaks detected on 4 and 5 December further suggest that vocal activity was not strictly restricted to nocturnal periods.

DISCUSSION

Acoustic monitoring as a complementary approach to visual surveys

A total of 4,567 fin whale calls were detected between 26 November and 25 December 2024, providing robust acoustic evidence of the species′ presence in the coastal waters off northern Japan during the boreal winter. This finding is further supported by ship-based visual sightings recorded in the same region during the autumn of 2019 (October–November), as reported by Katsumata and Matsuoka (2021). Their results indicate that fin whales utilized the coastal waters of northern Japan during the autumn season, lending additional support to the interpretation that this area serves as an important seasonal habitat for the species.

Our observations also recorded vocalizations from species other than fin whales and advancing species identification represents a future challenge. Long-term monitoring through PAM has been widely applied to investigate the seasonal and diel distribution patterns, migratory routes, population structure, and reproductive and social behaviors of cetaceans (Delarue *et al.*, 2009; Leroy *et al.*, 2016; Stafford *et al.*, 2007). Around the coast of Japan, it is necessary to increase the number of observation sites and conduct monitoring of species whose migration patterns are poorly understood.

In recent years, methods have been developed to adapt PAM to distance sampling for density estimation (Marques *et al.*, 2013). To advance from a qualitative presence/absence assessment of fin whales to a quantitative estimation of their population density, several technical challenges must be addressed: i) the source level distribution of 20-Hz pulses produced by fin whales in Japanese waters remains poorly characterized. Acoustic tagging efforts (e.g., Stimpert *et al.*, 2015; Watkins *et al.*, 1987) are expected to provide essential baseline data to address this gap; ii) converting detected calls into individual whale counts requires reliable estimates of how frequently a single whale produces vocalizations (e.g., Marques *et al.*, 2013); and iii) accurate modeling of sound attenuation in shallow environments such as continental shelves and slopes is crucial for estimating the effective detection range and probability of calls (e.g., Mellinger *et al.*, 2007).

To address the components above, the ICR is testing the development and deployment of archival acoustic tags. Figs. 7 and 8 show the designed acoustic tag and its

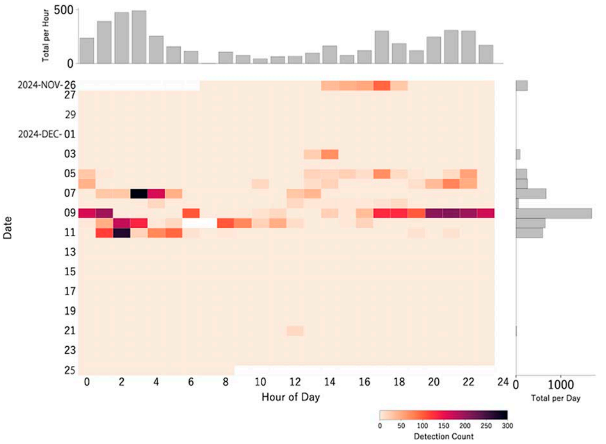

Figure 6. Hourly heatmap of fin whale call detections recorded in Ōhata, Aomori Prefecture, Japan, from 26 November to 25 December 2024. The x-axis indicates the hour of day (0–24), and the y-axis represents the calendar date. Color intensity reflects the number of detections per hour, with a notable concentration of vocal activity during nighttime hours. The bar plots above and to the right of the heatmap show the total number of detections per hour and per day, respectively. White gaps in the heatmap indicate periods of recorder replacement or data loss.

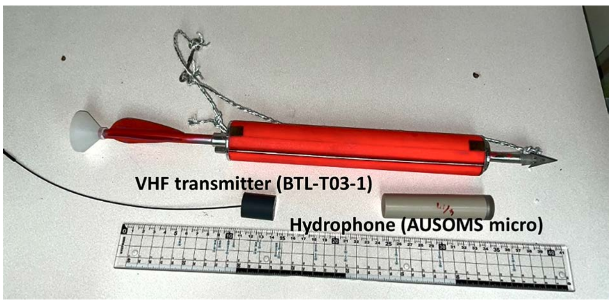

Figure 7. The acoustic tag designed and developed by the ICR. A VHF transmitter (BTL-T03-1, Circuit Design Inc.) is mounted for recovery purposes. The hydrophone uses AquaSound Inc.'s AUSOMS micro.

Figure 8. Acoustic tag deployment on a fin whale off Abashiri, May 2024. The tag was recovered 2 hours post-attachment.

deployment to fin whales. Once source-level estimation and calling rate quantification are established through acoustic tag deployment, distance sampling-based density estimation can be implemented. Another promising approach is the Spatially Explicit Capture–Recapture (SECR) method, which estimates animal density by modeling the spatial distribution of detections relative to sensor locations, and we plan to work on density estimation using this method in the future.

Temporal clustering and behavioral inference

Hourly detection trends revealed a pronounced diel rhythm in fin-whale vocal activity. Call counts were strongly concentrated during the night–early-morning period (18:00–08:00), and on 7, 9, 10 and 11 December hourly detections exceeded 300 calls. Similar nocturnal predominance has been reported elsewhere in the North Pacific (Širović *et al.*, 2015; Watkins *et al.*, 1987). Three non-mutually exclusive mechanisms may underline this pattern: i) endogenous behavioural rhythms associated with nocturnal foraging or social communication; ii) enhanced low-frequency propagation after sunset owing to changes in the sound-speed profile or reduced background noise; and iii) acoustic preference or timing of intra-specific information exchange restricted to specific hours.

Daytime detection bursts on 4 and 5 December indicate that calling is not exclusively nocturnal. Such unequal temporal distribution could also reflect transient aggregations of migrating animals or local environmental variability—e.g. prey density, water-column temperature structure or tidal flow. Because the present time series is relatively short and call samples are limited, a quantitative assessment of the ecological drivers is therefore premature.

ACKNOWLEDGEMENTS

This study was conducted as part of the 2024 Fisheries Agency of Japan's New Technology Development Project. We are deeply appreciative of the institutional support and guidance provided by Y. Fujise, K. Matsuoka, T. Hakamada and T. Isoda of the ICR. We would also like to express our sincere gratitude to the Ōhata Fisheries Cooperative, Nitto Seimo Co., Ltd., Marine Works Japan Ltd., and AquaSound Inc. Their invaluable support in the deployment and operation of the hydrophone system was essential to the success of this study. Finally, we wish to thank L.A. Pastene for his valuable input during the preparation of this report, and the TEREP Editorial Team for their careful editorial review.

REFERENCES

Clark, C.W. and Ellison, W.T. 2004. Potential use of low-frequency sounds by baleen whales for probing the environment: evidence from models and empirical measurements. pp. 564–582. *In*: J. Thomas, C. Moss and M. Vater (eds.) *Echolocation in Bats and Dolphins*. The University of Chicago Press.

Croll, D.A., Clark, C.W., Acevedo, A., Tershy, B., Flores, S., Gedamke, J. and Urban, J. 2002. Only male fin whales sing loud songs. *Nature* 417: 809–809.

Delarue, J., Todd, S.K., Van Parijs, S.M. and Di Iorio, L. 2009. Geographic variation in Northwest Atlantic fin whale (*Balaenoptera physalus*) song: Implications for stock structure assessment. *J. Acoust. Soc. Am.* 125: 1774–1782.

Furumaki, S., Tsujii, K. and Mitani, Y. 2021. Fin whale (*Balaenoptera physalus*) song pattern in the southern Chukchi Sea. *Polar Biol.* 44: 1021–1027.

Gómez-Rubio, V. 2017. ggplot2- Elegant Graphics for Data Analysis (2nd Edition). *J. Stat. Softw.* 77.

Katsumata, T. and Matsuoka, K. 2021. Results of the Japanese dedicated cetacean sighting surveys in the western North Pacific in 2019 and 2020. *Technical Reports of the Institute of Cetacean Research (TEREP-ICR)* 5: 16–32.

Leroy, E.C., Samaran, F., Bonnel, J. and Royer, J.-Y. 2016. Seasonal and Diel Vocalization Patterns of Antarctic Blue Whale (*Balaenoptera musculus intermedia*) in the Southern Indian Ocean: A Multi-Year and Multi-Site Study. *PLoS One* 11: e0163587.

Marques, T.A., Thomas, L., Martin, S.W., Mellinger, D.K., Ward, J.A., Moretti, D.J., Harris, D. and Tyack, P.L. 2013. Estimating animal population density using passive acoustics. *Biological Reviews* 88: 287–309.

Mellinger, D.K., Stafford, K.M., Moore, S.E., Dziak, R.P. and Matsumoto, H. 2007. An overview of fixed passive acoustic observation methods for cetaceans. *Oceanography* 20: 36–45.

Moore, S.E., Stafford, K.M., Dahlheim, M.E., Fox, C.G., Braham, H.W., Polovina, J.J. and Bain, D.E. 1998. Seasonal variation in reception of fin whale calls at five geographic areas in the North Pacific. *Mar. Mammal Sci.* 14: 617–627.

Nishida, S., Iwase, R., Kawaguchi, K., Matsuo, I. and Akamatsu, T. 2016. Fin whale calls observed with submarine cabled observatories off Kushiro-Tokachi during ten years. *OCEANS 2016 MTS/IEEE Monterey* 1–4.

Širović, A., Hildebrand, J.A. and Wiggins, S.M. 2007. Blue and fin whale call source levels and propagation range in the Southern Ocean. *J. Acoust. Soc. Am.* 122: 1208–1215.

Širović, A., Rice, A., Chou, E., Hildebrand, J., Wiggins, S. and Roch, M. 2015. Seven years of blue and fin whale call abundance in the Southern California Bight. *Endang. Species. Res.* 28: 61–76.

Stafford, K.M., Mellinger, D.K., Moore, S.E. and Fox, C.G. 2007. Seasonal variability and detection range modeling of baleen whale calls in the Gulf of Alaska, 1999–2002. *J. Acoust. Soc. Am.* 122: 3378–3390.

Stimpert, A.K., DeRuiter, S.L., Falcone, E.A., Joseph, J., Douglas, A.B., Moretti, D.J., Friedlaender, A.S., Calambokidis, J., Gailey, G., Tyack, P.L. and Goldbogen, J.A. 2015. Sound production and associated behavior of tagged fin whales (*Balaenoptera physalus*) in the Southern California Bight. *Anim Biotelemetry* 3: 23.

Sugioka, H., Kyo, M., Yoshida, R., Yamada, H. and Kato, H. 2015. Detection and characterization of whale signals using seafloor cabled seismic networks offshore Japan. *OCEANS 2015 - MTS/IEEE Washington* 1–7.

Tamura, T., Matsuoka, K. and Pastene, L.A. 2017. An overview of the research programs on large whales conducted by the Institute of Cetacean Research. *Technical Reports of the Institute of Cetacean Research (TEREP-ICR)* 1: 1–14.

Tsujii, K., Otsuki, M., Akamatsu, T., Matsuo, I., Amakasu, K., Kitamura, M., Kikuchi, T., Miyashita, K. and Mitani, Y. 2016. The migration of fin whales into the southern Chukchi Sea as monitored with passive acoustics. *ICES J. Mar. Sci.* 73: 2085–2092.

Watkins, W.A. 1981. Activities and underwater sounds of fin whales. *Sci. Rep. Whales Res. Inst*, 83–117.

Watkins, W.A., Tyack, P., Moore, K.E. and Bird, J.E. 1987. The 20-Hz signals of finback whales (*Balaenoptera physalus*). *J. Acoust. Soc. Am.* 82: 1901–1912.

Wiggins, S.M. and Hildebrand, J.A. 2007. High-frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring. *2007 Symposium on Underwater Technology and Workshop on Scientific Use of Submarine Cables and Related Technologies* 551–557.